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Comparison of Conventional Z-Source Inverter and Modified-Z-Source Inverters

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Abstract:
This paper investigates the performance analysis of the Modified-Z-Source Inverter with a simple voltage boost control method. The Z-Source network provides an efficient method of converting electricity in grid-connected solar applications, requiring only one step to fulfill the requirements. Nevertheless, high voltage stress and high voltage rating capacitor problems plague the Z-source inverter. In order to overcome these problems, a customised Z-network that maintains the same shoot-through duty ratio as a Z-source inverter is utilised to provide high boosted voltage. This research compares the performance of the modified Z-source inverter with the Z-source inverter using MATLAB.

Keywords: Z-Source Inverter, Modified-Z-Source Inverter, Voltage gain.

INTRODUCTION

Voltage boosting is now often needed for the majority of power electronic applications, especially solar systems that are directly linked to the grid. In a variety of electric power conversion applications, the electric power conversion between source and load is depicted in Fig. 1.

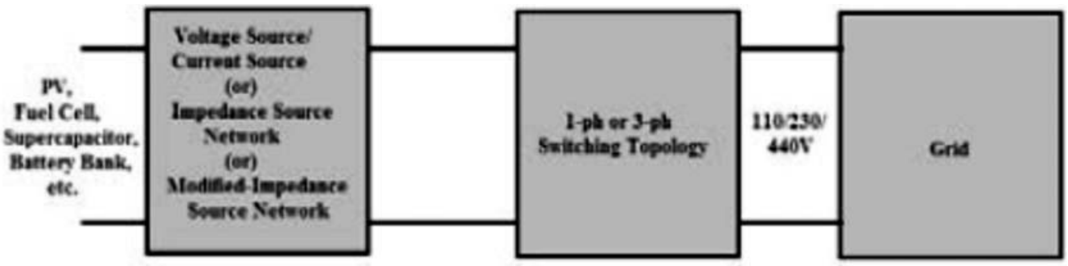

Fig. 1. Block diagram of electric power conversion between source and load.

The typical three-phase voltage source inverter (VSI) construction is seen in Fig. 2. The three phase bridge that serves as the primary converter circuit is fed by the DC voltage source, which is stabilised by a large capacitor. A battery, fuel stack cell, diode rectifier, or capacitor can be the source of DC voltage. The main circuit has six switches, each of which is typically made up of a power transistor and an anti parallel, or freewheeling, diode (D) to avoid unidirectional voltage blocking capacity and to allow bidirectional flow.(Source:)

Less AC voltage is produced at the output than DC voltage is supplied (buck inverter). The VSI is limited by the following:(Source:)[1]-[2]

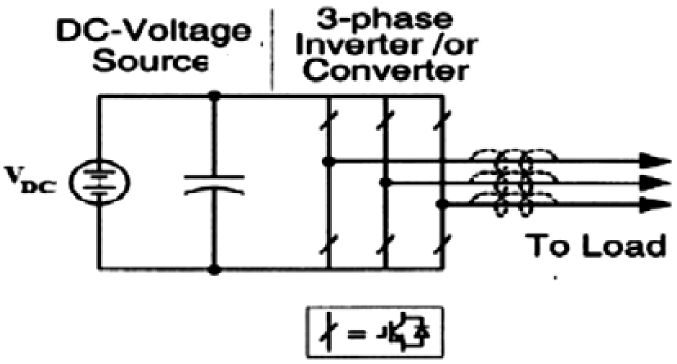

Fig. 2. Circuit diagram of Voltage Source Inverter.

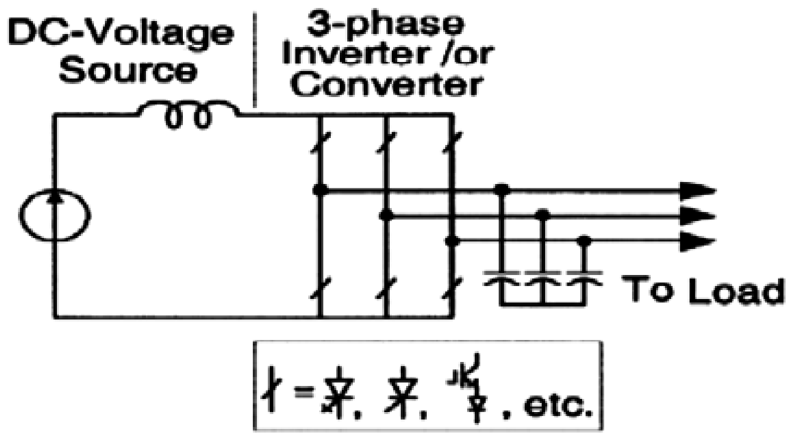

Fig. 3. Circuit diagram of Current Source Inverter.

• From the perspective of applications, an extra DC-DC boost (or buck) converter is required when a large range of voltage is desired.
*Each phase leg's upper and lower devices cannot be turned on at the same time.

The typical three-phase current source inverter (CSI) structure is seen in Fig. 3. Nine switching modes make up CSI, as opposed to VSI's six active modes and three zero modes. The boost inverter's AC output voltage exceeds its DC input voltage. Nevertheless, CSI is constrained by the following:

From an applications perspective, an extra DC-DC boost converter is required to provide the correct AC output voltage in cases when overdrive is desired. The one of the upper and lower devices have to be switched on simultaneously and should be maintained on at any instant.

In current source converter needed in the overlap time for safe current commutation and which is also a cause of waveform distortion, etc.

1. Z-SOURCE INVERTER

When compared to VSI and CSI, the Z-source inverter is a more sophisticated architecture since it does not require a DC-DC boost converter. The ZSI uses a combination of CSI and VSI to create an X-shaped linked network, or Z-source network, made up of two capacitors and two inductors. It benefits from one stage conversion and buck and boost operation.[1] – [4]

The traditional three-phase ZSI (Zimpedance Source Inverter) construction is seen in Fig. 4. Two identical inductors make up the Z-source network, while capacitors are linked diagonally and in series with each other. The shoot through condition, which occurs when two switches in the same leg are turned on simultaneously, allows the inverter to boost without causing any circuit damage. The traditional three-phase ZSI (Zimpedance Source Inverter) equivalent is seen in Fig. 5.

- Zero Mode
- Active Mode
- Shoot through Mode

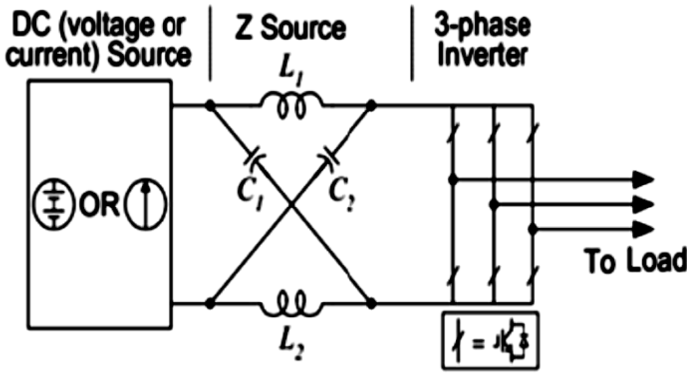

Fig. 4. Circuit diagram of Z-Source inverter

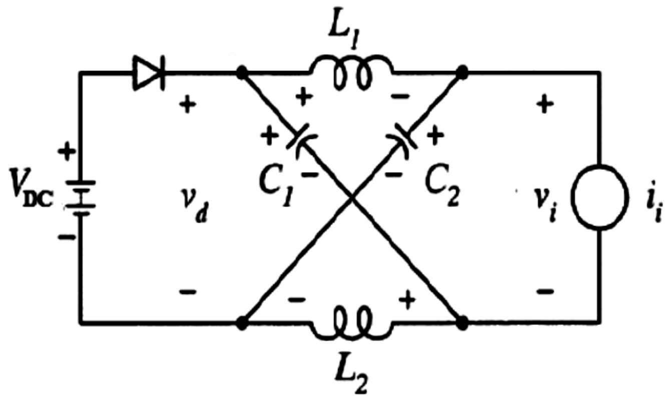

Fig. 5 Equivalent circuit diagram of the Z-Source inverter from the dc-link

2. ZSI EQUIVALENT CIRCUIT AND OPERATING MODESZERO MODE

ZSI has two zero modes in which the output voltage is zero. In this mode, upper (or) lower three switches are turned on simultaneously, thus acting as an open circuit and diode (D) is forward biased shown from Fig. 6. The capacitors (C_1 & C_2) and inductors (L_1 & L_2) are charged from the V_{DC}. In this mode the output AC voltage (V_{AC}) is zero.

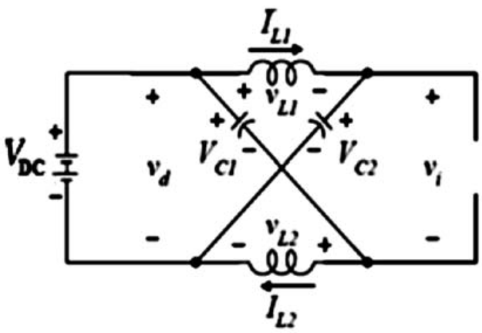

Fig. 6. Equivalent circuit diagram of ZSI in Zero Mode.

SHOOT THROUGH MODE

Shoot Through Mode arises when *Two switches in same leg (or) Two switches each from any two phases (or) All the six switches of three phases* conducts. Fig.7 shows the equivalent circuit of ZSI in shoot through mode. During shoot through mode energy is transformed from capacitor to inductor and hence ZSI gains the voltage boosting capability. In this mode, the diode (D) at input side is reverse biased.

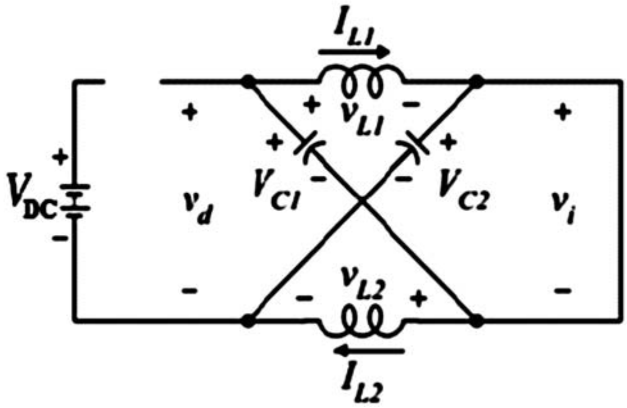

Fig. 7. Equivalent circuit diagram of ZSI in Shoot through Mode.

Assuming a similar impedance network ($C_1 = C_2 = C$ and $L_1 = L_2 = L$), it can be observed that :

$V_{L1} = V_{L2} = V_L$ (1)

$V_{C1} = V_{C2} = V_C$ (2)

$V_C = V_L$ (3)

$V_d = 2 * V_C$ (4)

The dc-link voltage across inverter during shoot through time period (T_0) is

NON-SHOOT THROUGH MODE

It has six non shoot through states. As shown in fig.8 when the three phase inverter (V_i) switches are one leg positive switch and other leg negative switches are shorted. It this mode, the diode (D) at input sideforward biased and capacitors are charge (or no action) and inductors are discharge.

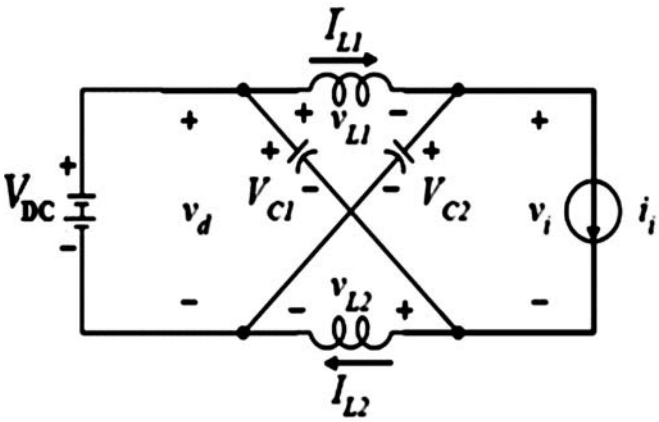

Fig. 8. Equivalent circuit diagram of ZSI in non-Shoot through Mode.

The dc-link voltage across the inverter during non-shoot through interval (T_1) is,

$V_d = V_{DC}$ (5)

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$$V_i = 2 * V_C - V_{DC} \quad (6)$$
$$V_i = B_f * V_{DC} \quad (7)$$

The ZSI suffers from the following drawbacks:

- Unable to maintain the inductor current's flexibility.
- The input voltage is less than the voltage across the capacitor.
- The modulation index employed is lower the higher the voltage boost gain.
- There is a high voltage tension.

In summary, despite their widespread usage, the standard three-phase inverters (VSI & CSI) and impedance-source inverters (ZSI) have some drawbacks that ultimately reduce circuit performance and raise system expenses..

3. TRANS-Z-SOURCE INVERTER

The Trans-Z-Source Inverter is a new topology in power conversion. Trans-z-source inverter extends the Z-Source inverter concept to Transformer-based Z-Source inverter. These inverters have two inductors which can be replaced by a magnetic coupled inductor. By doing so, the two inductors are coupled through magnetic field and one capacitor can be removed thus reducing the capacitor count

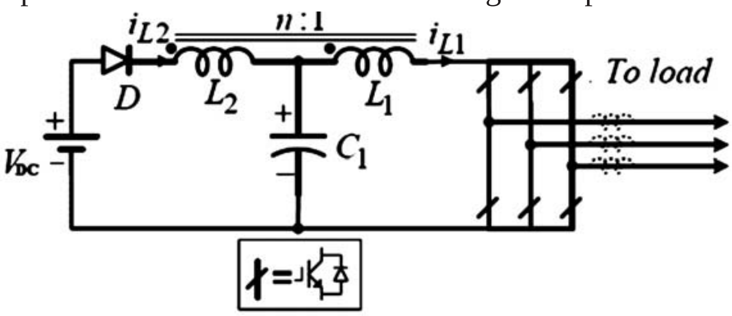

Fig. 9. Circuit diagram of Trans-Z-Source Inverter (Trans-ZSI).

As shown in fig.9 when the Trans-ZSI has the turn ratio one the inverter dc-link voltage boost gains same with the ZSI. The turn ratio is over one($n > 1$). The inverter voltage boost gains high in the same modulation index. The transformer should be designed with low leakage inductance & very high transformer is difficult to implement. The DC-AC voltage gain cannot exceed two in the boost operation. The Trans-ZSI suitable for low to medium power applications.

VOLTAGE-FED-TRANS-Z-SOURCE INVERTER

The Main & equivalent circuit of Voltage-Fed-Trans-ZSI are shown in Fig.10& Fig.11. In the voltage fed tans-ZSI with continuous input current two inductors can be coupled. Coupled inductor has the property of reflecting the voltage across the inductor L_1 to inductor L_2 through magnetic coupled. Here the coupled inductor turns ratio should be chosen as 2:1. These kinds of trans-ZSI has properties of buck-boost operation, single stage conversion and low dc voltage of capacitor (C_1), increases the voltage gain and decreases the voltage stress

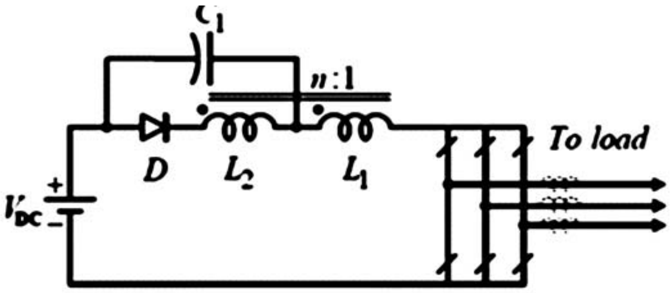

Fig. 10. Circuit diagram of Voltage-Fed-Trans-Z-Source Inverter.

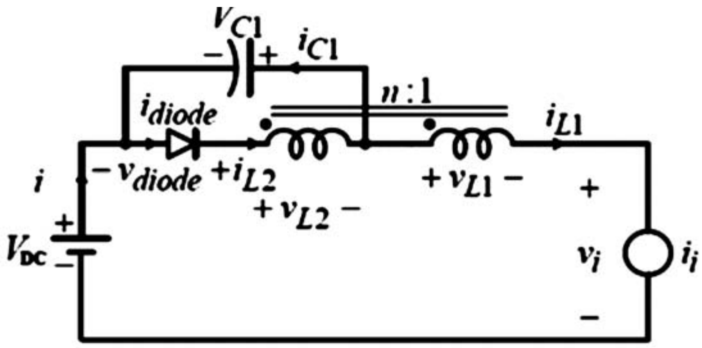

Fig. 11. Equivalent circuit diagram of Voltage-fed-Trans-ZSI.

SHOOT THROUGH MODE

It is same as same traditional ZSI operation. It is also one shoot trough state (The three phase inverter switches are shorted through (turn on simultaneously) both upper and lower of any one leg and two legs or three legs). The diode (D) is reverse biased (because the cathode voltage is greater than the anode voltage). The capacitor C1 is discharge. The equivalent circuit diagram in the shoot through mode is shown in Fig.12.

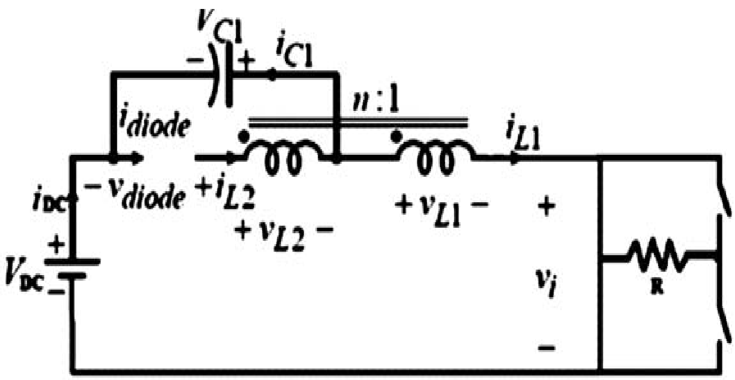

Fig. 12. Equivalent Circuit diagram of Voltage-fed-Trans-ZSI in Shoot though Mode.

NON-SHOOT THROUGH MODE

Its have six non shoot through modes. When the three-phase inverter (Vi) switches are one leg positive switches and other leg negative switches are shorted. In this state the diode (D) at input side forward biased and capacitor (C_1) is charged. The equivalent circuit diagram in the non shoot through mode is shown in fig.13.

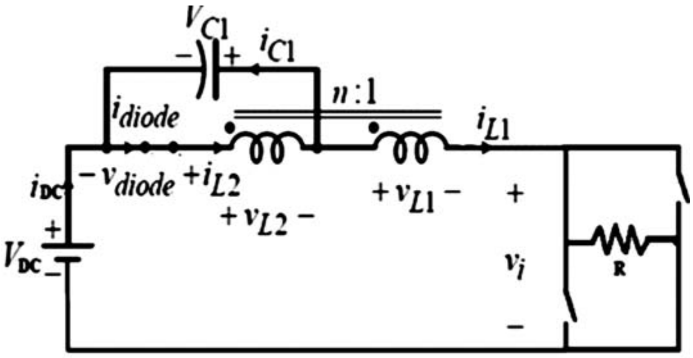

Fig. 13. Equivalent circuit of Voltage-fed Trans-ZSI in Non-Shoot through Mode

4. PWM TECHNQIUES FOR ZSI

Simple Boost Method

This method uses two straight lines of equal magnitude with opposite polarities are used. To insert shoot through state the magnitude of carrier wave must be greater than the carrier. In this method all carriersare in phase opposition with the neighbour carriers & it is called as Alternate Phase Opposition Disposition (APOD). When the carrier waveform is greater than the upper constant, or lower than the bottom constant line the circuit goes into shoot through state. Otherwise it operates as a conventional carrier based PWM. This method is very simple. However, the resulting voltage stress across the switches is relatively high because some traditional zero states are not utilized.

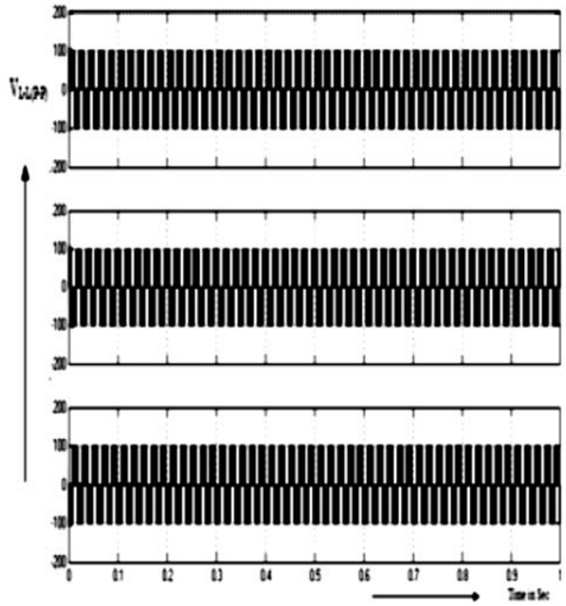

Fig. 14. (*a*) Output voltages for the traditional Trans Z-source inverters

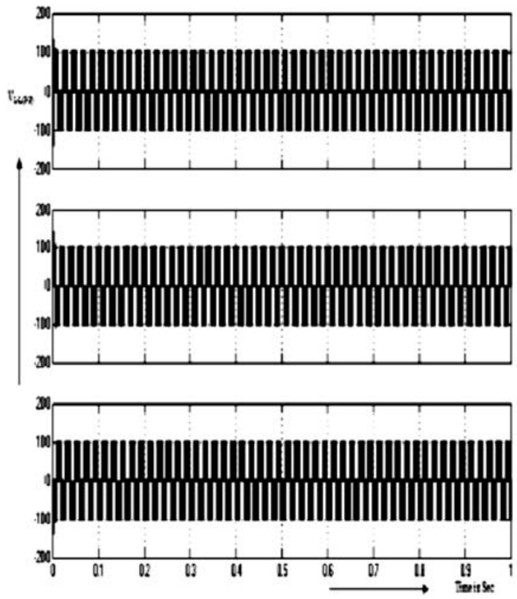

Fig. 14. (*b*) Output voltages for the Z-source inverter

To verify the advantages of the proposed Trans-ZSI, MATLAB simulation compares and performance with the traditional ZSI for boost operation. The simulation result of proposed work will validate with ATLAB software. THDs (Total harmonic distortions) analysis are also validate with FFT analysis of MATLAB software for compare to the Trans-ZSI and ZSI.We selected parameters C = 1000F and R =

50ohms/phase. The turns ratio of the transformer is n = 2. The magnetic inductance (L_m) was set to 0.4145mH. The magnetization resistance (R_m) was set to 0.091 ohms.

The switching frequency was 10kHz, the input DC voltage 100(V_{DC}). Simple boost control was used. To compare the traditional ZSI and Trans-ZSIof simulation results was shown in fig.14,15 & 16.

Fig. 14(a) & (b) shows output voltages for the traditional Z-source inverter and Trans-z-source inverters when modulation index (M.I) = 1, the shoot through duty ratio is zero ($D_{st} = 0$) ,boost factor is 1 (B_f = 1), the voltage gain also 1 (G = 1). Then the Z-source and Trans-Z-source inverters act as normal inverter in non shoot through mode. Because of the output voltages (V_{AC}) are equal to input DC voltage (100 Volts).

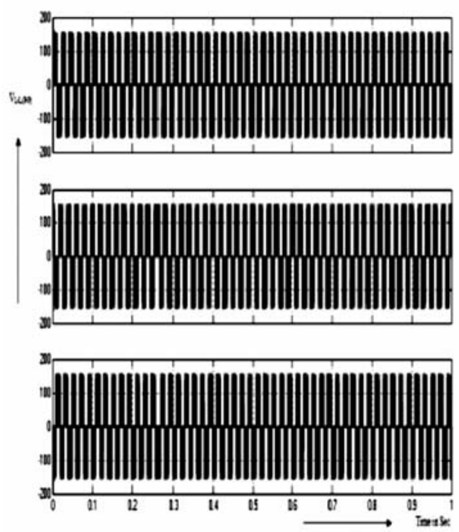

Fig. 15. (a) Output line to line voltages for the voltages for the traditional Z-source inverter

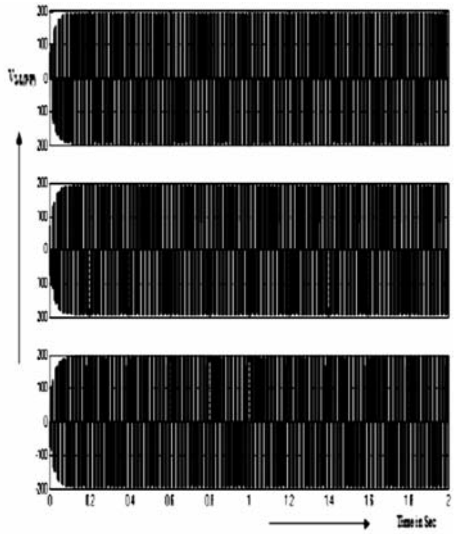

Fig. 15. (b) Output line to line Trans Z-source inverters

From Fig. 15 (a) & (b) shows compare to the output voltage (line-line) wave forms for traditional Z-source and Trans-Z-source inverters. In traditional Z-source inverter have modulation index is equal to the 0.85(M.I = 0.85), the shoot through duty ratio is 0.15(D_{st} = 0.15), the boost factor is equal to 1.428 (B_f = 1.428) and voltage gain is equal to 1.2138 (G=1.2138). In Trans-ZSI also used same modulation index (M.I = 0.85), the shoot through duty ratio is obtained like as traditional ZSI, but to varying the boost factor and voltage gain (*i.e.*, B_f = 1.818 and G = 1.5453). The traditional Z-source inverter of the output voltage (peak-peak) is 150Volts (V_{rms} = 113Volts) and proposed Trans-Z-source inverter of the output voltage (peak-peak) is 200Volts (V_{rms} = 143Volts). Then, in this case ZSI and Trans-ZSI act as the shoot through mode operation. The Trans-ZSI obtains a voltage boost with same modulation index and same shoot through duty ratio and input DC voltage (V_{DC} = 100Volts) as compare to the ZSI. When turns ratio is equal to the (n = 1), it is the same output voltage (V_{AC}) in traditional ZSI. When $n > 1$, the Trans-Z-sourceinverter voltage is boosted compare to the ZSI.

Fig. 16.(a) and (b) shows compare to the voltage across switch, rms and mean voltages for traditional ZSI and proposed Trans-ZSI. In traditional ZSI have modulation index 0.85(M.I = 0.85), shoot through

duty ratio is 0.15; we obtain the voltage across switch 150 Volts, the rms voltage vary 80-100Volts, and mean voltage vary 50-70Volts. In same modulation index and shoot through duty ratio of Trans-ZSI we obtain the voltage across switch 200Volts, the rms voltage vary 100-130Volts, and mean voltage vary 60-90Volts. The voltage stress depends up on the transformer windings (or turns ratio). By increase the turn's ratio the voltage across switch or voltage stress) is decreases.

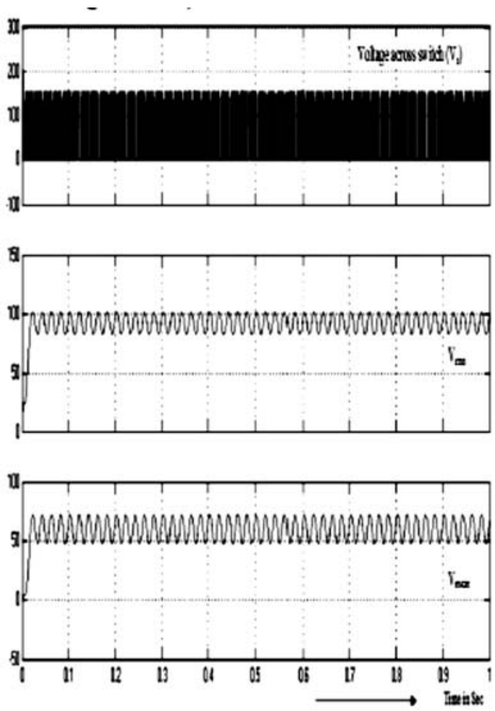

Fig. 16. (*a*) simulation results of oftraditional Z-source inverter

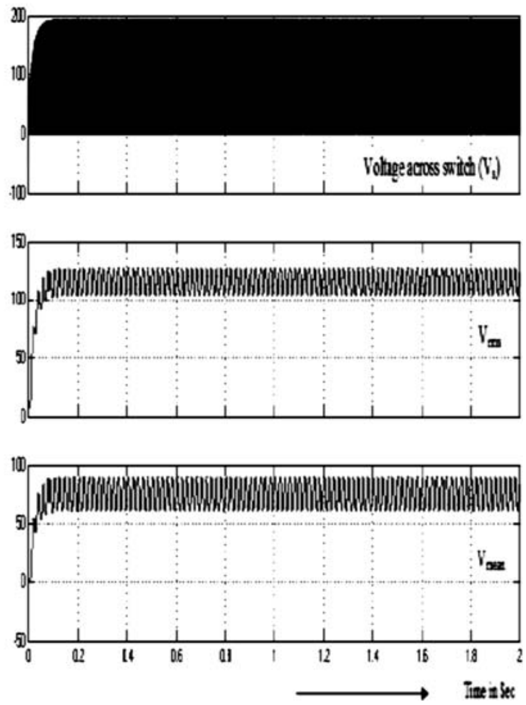

Fig. 16. (*b*) simulation results Trans Z-source inverters

Fig. 17 (*a*) and (*b*) shows simulation results of traditional ZSI and Trans-ZSI. In FFT analysis, fundamental frequency 50Hz and the modulation index 1 and shoot through duty ratio zero. We obtain nearly same FFT analysis of the traditional ZSI and Trans-ZSI.

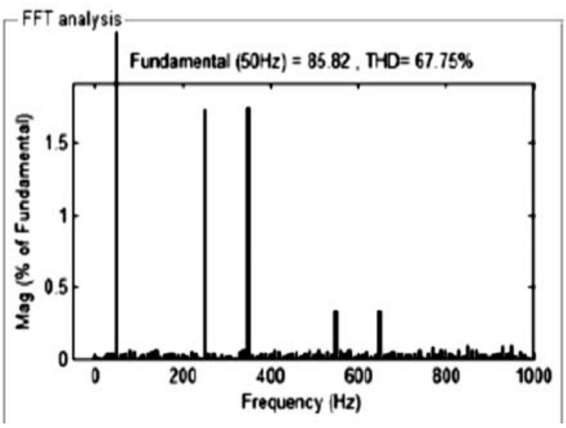

Fig. 17. (*a*) FFT analysis of traditional Z-source inverter

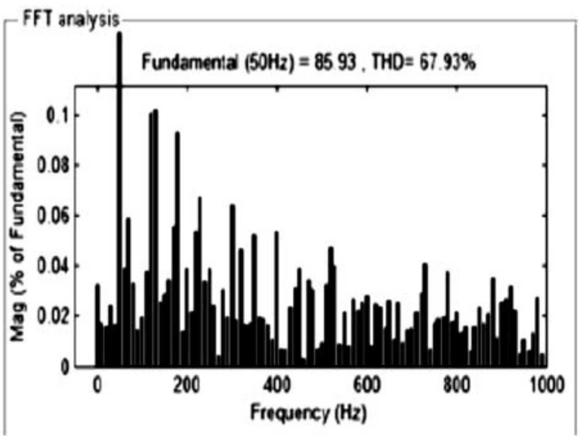

Fig. 17. (*b*) FFT analysis of Trans Z-source inverters

5. CONCLUSION

Two key features of the novel topology for the Modified-Z-source inverter are its high boost voltage inversion capacity and its ability to lower voltage stress. Modified Z-source inverters, as opposed to standard Z-source inverters, have lower input current ripple, less voltage stress on the dc-link, and less current stress flow to the transformer winding and diode, all of which contribute to a greater modulation index. In comparison to normal ZSIs, the modified ZSI employs a lower transformer turns ratio to generate the same input and output voltage if the modulation index is maintained unchanged. Modified Z-source inverters, for example, show great promise in situations where the input voltage is very low, such mini inverters for solar systems. The analysis and feature have been validated by simulation results using both the modified-ZSI and the traditional ZSI.

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